

OVERVIEW OF AEROTHERMODYNAMIC LOADS DEFINITION STUDY

Raymond E. Gaugler
NASA Lewis Research Center

527-39
19884

For a number of years now, NASA has been conducting the Advanced Earth-to-Orbit (AETO) Propulsion Technology Program, now part of the Civil Space Technology Initiative (CSTI) Program. The program objective is to provide the knowledge, understanding, and design methodology that will allow the development of advanced Earth-to-orbit propulsion systems with high performance, extended service life, automated operations, and diagnostics for in-flight health monitoring. This program supports both current and future engine and vehicle developments. The technology needs of the current Space Shuttle Main Engine (SSME) have thus far provided the main focus for the AETO efforts. Organizationally, the program has been divided into technology working groups made up of people from both the Marshall Space Flight Center and the Lewis Research Center. The focus of this report is the Lewis effort under the Fluid and Gas Dynamics working group, the Aerothermodynamic Loads Definition Study.

The objective of the Aerothermodynamic Loads Definition Study is to develop methods to more accurately predict the operating environment in AETO propulsion systems, such as the Space Shuttle Main Engine (SSME) powerhead. Development of time-averaged and time-dependent, three-dimensional viscous computer codes as well as experimental verification and engine diagnostic testing are considered to be essential in achieving that objective. Time-averaged, nonsteady, and transient operating loads must all be well defined in order to accurately predict powerhead life. Improvements in the structural durability of the SSME turbine drive systems will depend on our knowledge of the aerothermodynamic behavior of the flow through the preburner, turbine, turnaround duct, gas manifold, and injector post regions.

The approach taken under this study consists of two parts: (1) to modify, apply, and disseminate existing computational fluid dynamics (CFD) tools in response to current needs and (2) to develop new technology that will enable more accurate computation of the time-averaged and unsteady aerothermodynamic loads in the SSME powerhead. The new technology development effort is further divided into three parts: (1) new computer code development, (2) experiments to provide data for physical models required by the codes, and (3) experiments to provide data for validating the codes. With the more accurate aerothermodynamic load predictions providing boundary conditions to improved structural and fatigue life analyses, the goal of improved durability will be met.

The Aerothermodynamic Loads Definition Study was begun in October 1983. The initial effort involved the use of existing CFD tools to analyze problems in the fuel and oxidizer turbopump turbines, the fuel turbine turnaround duct, the fuel-side preburner, and the main injector liquid oxygen posts. Results

of those efforts have been presented previously and will not be discussed here. What follows is a description of the currently active tasks and their status.

H4(a). UNSTEADY VISCOUS MULTIBLADE-ROW TURBINE ANALYSIS

In this task, the objective is to develop a numerical simulation capability for unsteady viscous flow and heat transfer in multiblade-row turbines.

The numerical simulation of unsteady viscous flows in multiblade-row turbines requires a means of reducing the three-dimensional, nonperiodic, multi-row problem to one of more manageable proportions. This work will develop a two-dimensional test bed to be used in exploration for ways of solving the full problem. The approach is to use an existing quasi-3D viscous cascade code as the basis of a 2D multipassage rotor-stator interaction code.

A detailed description of the latest efforts under this task will be presented later in this session.

H4(b). COMPUTATION OF THREE-DIMENSIONAL FLOW WITH HEAT TRANSFER

In this task the objective is to develop an accurate, efficient numerical analysis of steady 3D viscous flow and heat transfer in turbine blade rows.

The approach being taken is to modify a 3D viscous turbomachinery code (RVC3D) to include an advanced turbulence model and increased resolution of near-wall gradients and to validate and upgrade the code by application to suitable 3D data sets.

H4(e). THREE-DIMENSIONAL STATOR-ROTOR BLADE FLOW EXPERIMENT

The objective of this task is to investigate the steady and unsteady 3D viscous flow field in an axial turbine stage, including stator-rotor interaction, mixing effects, blade and end wall boundary layers, and temperature gradient effects on secondary flow development. This work is being done in the Pennsylvania State University Axial Flow Turbine Research Facility. A progress report will be presented later in this session.

H4(m). TURBULENCE MODELING FOR PROTEUS TURBOMACHINERY CODE

The objective of this task is to develop the capability to predict turbulent flow losses and heat transfer in the SSME turbines using the Proteus 3D Navier-Stokes code. Existing turbulence models are inadequate or require empirical tuning to generate reasonable results. Efforts have begun, working first with a 2D version of the code.

H5(a). IMPROVED MODELING, PREBURNER FLOW

In this task the objective is to obtain steady-state reacting hydrogen data of mean and fluctuating velocities and concentrations and to compare

benchmark data with predictions from computer models and evaluate turbulence-chemistry interactions.

Computations of the 3D flow in the SSME turbopump turbines requires knowledge of the condition of the gases exiting the preburner. Current models for predicting those conditions are inadequate. Fluctuating concentration and velocity data can now be obtained with laser diagnostics. These measurements are necessary to determine the unmixedness of the reacting flow and the reaction rates. The measurements are also necessary for differentiating the various computer models.

For this task a team of computer modelers and experimentalists have defined the measurements required to verify turbulent-reacting flow models. Existing optical techniques will be used to make measurements within the shear layer: two-component laser Doppler velocimetry (LDV), fluorescence for OH and temperature, and $TiCl_4$ for seeding and H_2O concentration.

Hardware fabrication is nearly complete. Figure 1 is a schematic view of the test rig, and figure 2 is a photograph of the test section, mounted in an inspection facility.

H5(f). HIGH REYNOLDS NUMBER AND UNSTEADY HEAT TRANSFER EXPERIMENT

In this task the objective is to develop a fundamental understanding of the effects of high Reynolds numbers and Reynolds number variations, and also upstream unsteadiness, on heat transfer in turbulent boundary layers typical of turbine airfoils in the SSME turbopump turbines.

In order to predict the surface pressure and temperature distributions within engine flow passages, an accurate turbulence and unsteadiness model is needed. Data in the proper range of Reynolds number and disturbance frequency are necessary for accurate modeling. A new in-house experimental rig, shown schematically in figure 3, is being built in which the major features of an SSME turbine airfoil will be simulated, particularly the Reynolds number. A particular feature of the rig will be the ability to span the Reynolds number range from conventional gas-turbine levels up to SSME levels. Figure 4 is a photograph of the test section, instrumented and awaiting installation in the facility. Testing will be underway in the near future.

H5(g). UNSTEADY HEAT TRANSFER ANALYSIS

In this task the objective is to formulate analytic models to aid in the prediction of the unsteady aerothermal loads expected in the SSME turbopump turbines.

The ability to predict the aerothermal loads in the turbine unsteady flow environment is an essential input to the ability to predict life and durability. There are two aspects to the unsteadiness which occurs on turbine blades. The first is due to free-stream turbulence and wakes shed from upstream vanes and blades. The second is due to laminar to turbulent boundary layer transition which occurs some distance downstream from the blade leading edge. Both of these issues are being addressed in this research program.

For the unsteady wake interaction problem, a viscous-inviscid boundary layer theory has been used to model the effects of passing wakes and free-stream turbulence on the heat transfer to the SSME turbine airfoils, particularly near the stagnation region. For the boundary layer transition experiments, an experimental approach is being used to study the effects of concave curvature, which occurs on the pressure side of the SSME turbine airfoil, during the transition process.

H5(h). IMPROVED AERO AND HEAT TRANSFER PREDICTION

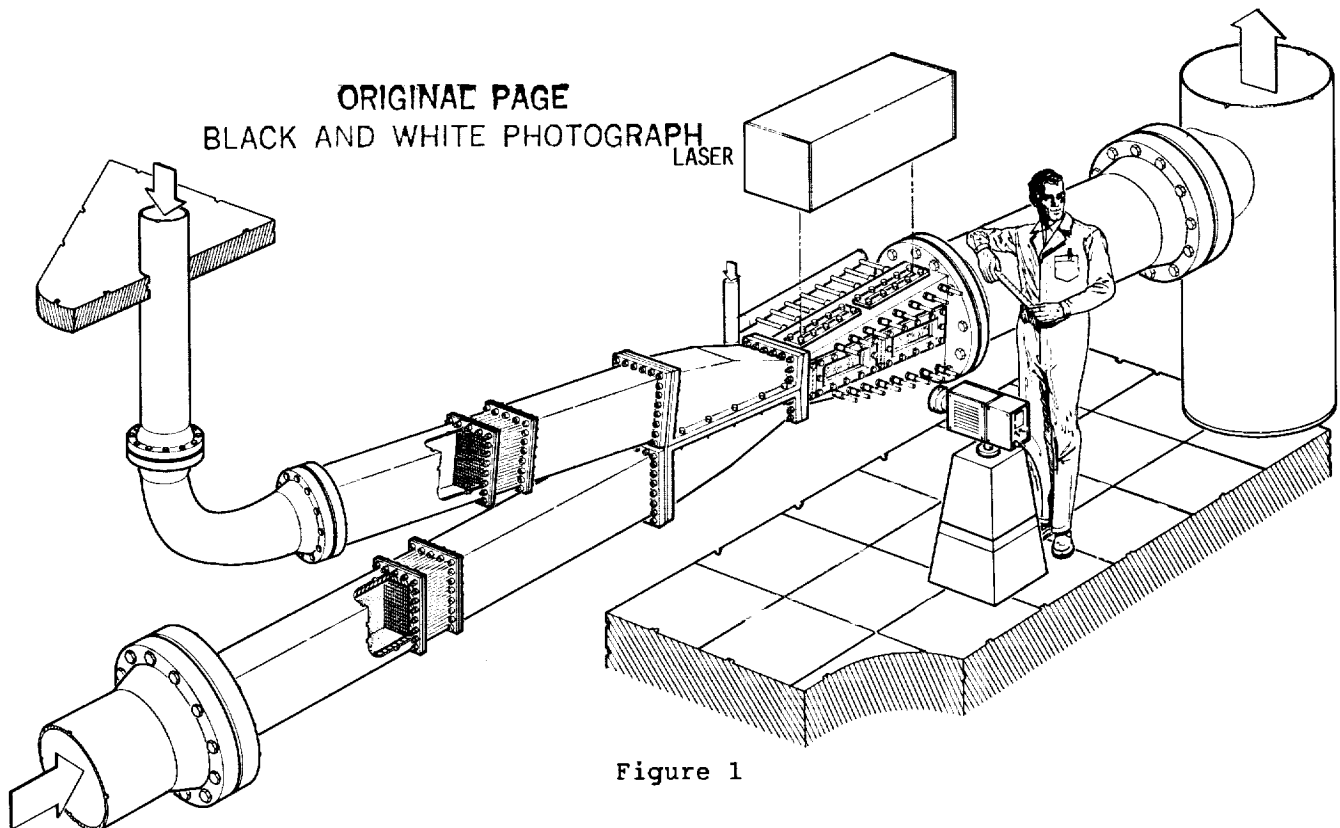
In this task the objective is to improve the calculation of the aerodynamic environment in low-aspect-ratio turbines and to experimentally obtain the unsteady surface heat transfer response to a temperature disturbance.

Knowledge of the local flow environment of turbine vanes and blades is essential for the accurate prediction of turbine temperatures and heat-transfer rates. In addition, the response of the turbine blade surfaces to rapid changes in stagnation temperature is unknown. Improved steady and unsteady heat transfer prediction is required for improved life and for turbine efficiency. An existing quasi-3D computer code will be activated at Calspan and used to compute pressure distributions over stator and rotor surfaces, substantially reducing the uncertainty in the aerodynamic environment and providing a reliable base for heat transfer predictions. The experimental phase will use a low-aspect-ratio turbine instrumented with thin-film heat flux sensors located on the vanes and rotor blades. The temperature level, disturbance, blade passing frequency, and Reynolds number will be varied. A detailed description of the latest results under this task will be presented in another paper at this meeting.

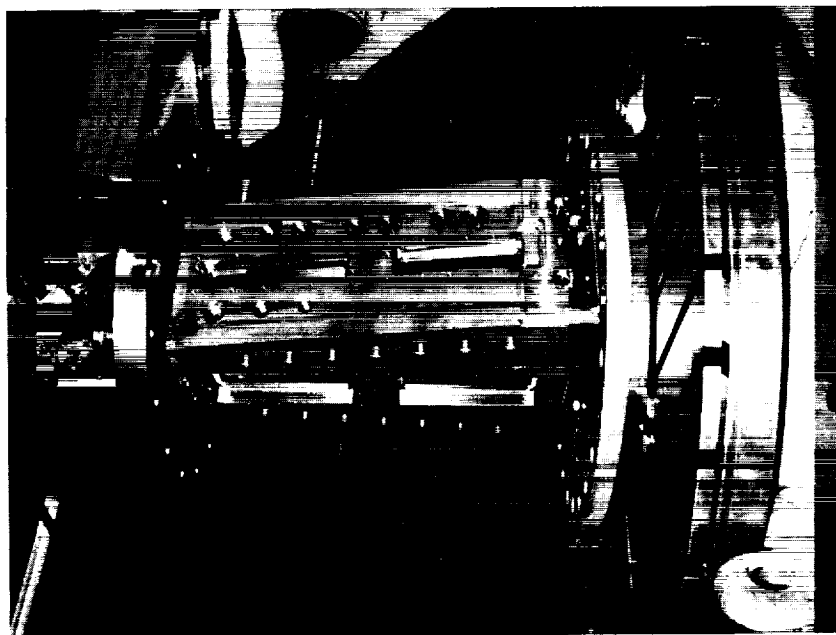
SUMMARY

Significant progress is being made in the Aerothermodynamic Loads Definition Study, particularly in the turbomachinery area, where there is a distinct overlap between the AETO efforts and research in the aeronautical gas turbine field. The continuing work under this program will provide the knowledge, understanding, and design methodology that will allow the development of advanced Earth-to-orbit propulsion systems with high performance, extended service life, automated operations, and diagnostics for in-flight health monitoring.

PLANAR REACTING SHEAR LAYER



SSME AERO-THERMODYNAMIC LOADS FLUID AND GAS DYNAMICS WORKING GROUP



CD-89-39277

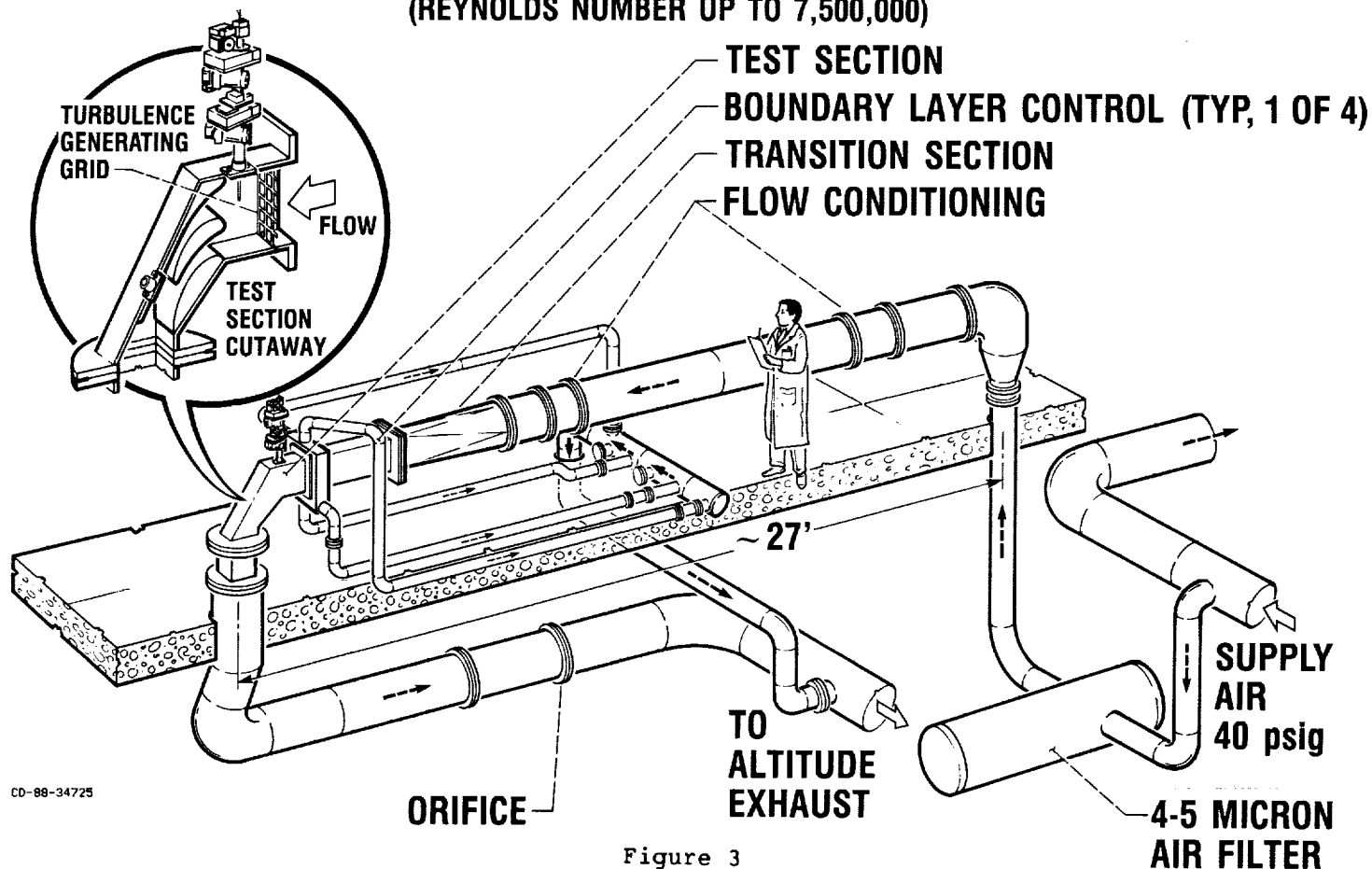
Figure 2

ORIGINAL PAGE IS
OF POOR QUALITY

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

HIGH REYNOLDS NUMBER HEAT TRANSFER RIG

(REYNOLDS NUMBER UP TO 7,500,000)



CD-88-34725

Figure 3

HIGH REYNOLDS NUMBER & UNSTEADY HEAT-TRANSFER RIG TEST SECTION

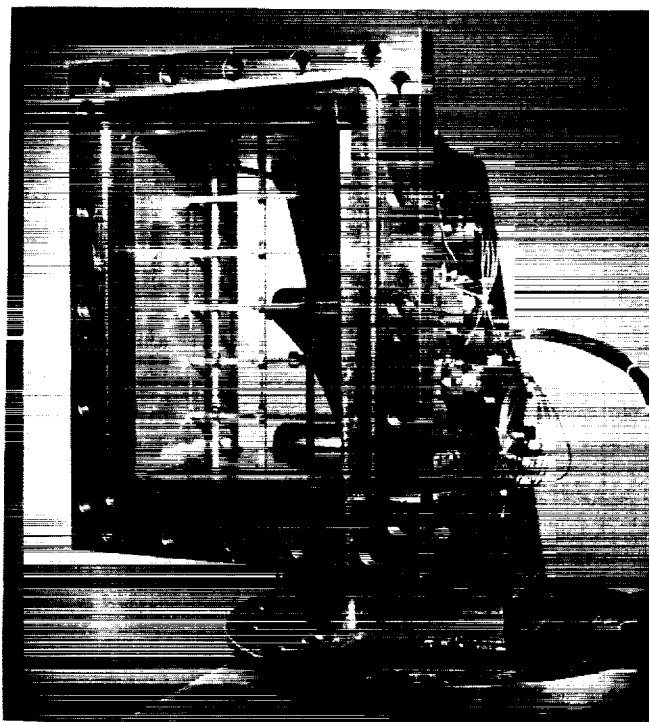


Figure 4

CD-89-39276